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Multi-criteria selection of offshore wind farms: Case study for the Baltic States

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ABSTRACT

This paper presents a multi-criteria selection approach for offshore wind sites assessment. The proposed site selection framework takes into consideration the electricity network's operating security aspects, economic investment, operation costs and capacity performances relative to each potential site. The selection decision is made through Analytic Hierarchy Process (AHP), with an inherited flexibility that aims to allow end users to adjust the expected benefits accordingly to their respective and global priorities. The proposed site selection framework is implemented as an interactive case study for three Baltic States in the 2020 time horizon, based on real data and exhaustive power network models, taking into consideration the foreseen upgrades and network reinforcements. For each country the optimal offshore wind sites are assessed under multiple weight contribution scenarios, reflecting the characteristics of market design, regulatory aspects or renewable integration targets.

1. Introduction

The European Union (EU) has set ambitious goals with respect to energy and environmental impact, the renewable energy directive sets a target of reaching 20% of final energy consumption from renewable energy sources by 2020 (Official Journal of the European Union, 2009). The European Commission (EC), in their 2030 impact assessment for climate and energy policy framework, identified the need for renewable energy shares in the final energy consumption ranging from 25% to 27% in 2030 and from 30% to 51% in 2050, translated in the mid-term in a renewable electricity share between 43% and 47% in 2030 (European Commission, 2014). Considering these projections, at least 21% of the renewable shares is expected to be provided by wind power generation (European Commission, 2014). The total installed capacity in the EU has seen an increase of 3.8% compared to 2013 levels and 29.4% since 2000, representing a compound annual growth rate of 9.8% (THE EUROPEAN WIND ENERGY ASSOCIATION, 2015). On the other hand, the offshore installed capacity still accounts only for 7% of installed capacity in the EU,[1] median projection of new capacities in 2030 are mostly located in the Nordic and Baltic Seas with respectively 45 GW and 8 GW of total installed capacity (European Wind Energy Association, 2015).

Cavazzi and Dutton (2016) proposed a Geographical Information System (GIS) based tool for assessing the UK's offshore wind energy potential, the tool provide a stakeholder neutral evaluation considering economic factors such as the development cost, maintenance and production yield - derived from average wind speed. Atici et al. (2015), proposed an AHP based multiple criteria decision making for wind farms site selection, the proposed site selection methodology relies on two stages namely pre-elimination and evaluation of the remaining alternatives. Several criteria have been identified to reflect the interest of three stakeholders: investors, regulators and civil society - the identified criteria reflect mainly the financial impact in terms of connection costs and energy yield. Sánchez-Lozano et al. (2016), proposed a Fuzzy AHP to obtain weights relevance for the identified criteria consisting of the wind site distance to cities, power lines/ substations, telecommunication infrastructures and energy yield based on average wind speed. The proposed approach had the advantage of processing both quantitative and qualitative criteria. Fetanat and Khorasaninejad (2015) proposed a hybrid multi-criteria decision making tool using fuzzy logic derived processes for offshore wind sites selection based on depth, environmental, technical resources and economic aspects. In fact, optimal selection of wind site projects has been extensively addressed in the literature, with the aim to identify the

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[1] The Wind Energy Association (EWEA) projects in their most conservative scenario the doubling of the installed capacity by 2014 (129GW) to 251GW in 2030, 66GW of which is offshore wind resulting in an expected 19% share of the EU electricity demand.

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Nomenclature

A	Wind turbine's blade swept area [m^2]
B'_s	Normalized Balancing criteria at a site *s*
c	Weibull function scale parameter
$C'g_s$	Normalized congestion criteria for the site *s*
$C'r_s$	Normalized correlation criteria at a site s
Cf'_s	Normalized capacity factor criteria at a site *s*
C_p	Wind turbine power coefficient
f_s	Wind speed Weibull distribution function for a site *s*
I'_s	Normalized investment cost criteria
k	Weibull function shape parameter
L_i	the load at the hour i within a control area
N	Number of points
NL_i	the net load at the hour *i* within a control area
OC_s	Cost objective at a site *s*
OP_s	Performance objective at a site *s*
OR_s	Reliability objective at a site *s*
P_C^{Sys}	Aggregated Contingency Overload
$Pmax_s$	Aggregated wind power generation at a site *s*
P_s	Aggregated wind power generation at a site *s*
Pw_i	the wind power generated at the hour *i* within a control area
R_s	Reliability criteria at the site *s*
$Tl_{j,k}$	Thermal limit of the line connecting the bus *j* to the bus *k* [MW]
T_s	Final score for the aggregated criteria at the site *s*
$\bar{u}$	Average measured wind speed
u_i	Wind speed measurement
u_r	Wind speed at a reference height z_r
v_m	Wind meridional velocity component
v_z	Wind zonal velocity component
V'_s	Normalized volatility criteria at the site *s*
W_{CB}	Weight adapting the balancing criteria
W_{CI}	Weight adapting the investment criteria
W_{PC}	Weight adapting the correlation criteria
W_{PCF}	Weight adapting the capacity factor criteria
W_{RC}	Weight adapting the Congestion criteria
W_{RV}	Weight adapting the Volatility criteria
z	Height of the estimated wind speed
z_r	Reference height for the measured wind speed
α	Atmospheric stability empirical factor
$\Delta Ld_{j,k}$	Overloading in % of line connecting the bus *j* to the bus *k*
μ	Wind speed expected mean value
ρ	Air density [kg/m^3]
σ_L	Load standard deviation
σ_{NL}	Net load standard deviation
σ_w	Wind power generation standard deviation.

most appropriate location for investment while considering mainly the benefits in term of energy yield, environmental impact and cost using GIS tools and techniques (Atici et al., 2015; Cavazzi and Dutton, 2016; Gorsevski et al., 2013; Latinopoulos and Kechagia, 2015; Lee et al., 2009; Mekonnen and Gorsevski, 2015; Sliz-Szkliniarz and Vogt, 2011; Van Haaren and Fthenakis, 2011).

It is clear that in order to reach the expected targets, within a reliable fully integrated EU electricity network, necessary infrastructure investment has to be foreseen, as well as the allocation of extra costs to mitigate the intermittency effect of such resources (i.e. ancillary services, network reinforcement, demand side management etc.). Against this background, it is critical for policy makers to take into consideration all the parameters affecting electricity networks operators, investors, utilities and consumers. This has to be achieved by capturing the interaction between the different actors and determining where capacity can be developed in the most cost-effective way.

While the economic aspect has been exhaustively assessed as a key factor for wind sites selection - reflecting mainly the producer surplus in term of energy yield and investment costs - the economic consumer surplus has not been adequately evaluated by considering the impact of a candidate project in term of subsequent operational expenditure (OPEX) cost. In fact, whereas a site can present optimum characteristics in term of energy yield or environmental impact, its integration at a certain network location can result in substantial higher OPEX costs to preserve the overall reliability and security of supply levels. In that perspective, the Transmission System Operators (TSO) shall be considered as a relevant stakeholder for a comprehensive evaluation taking into consideration the power system component in gauging the impact of each potential site in term of risks and operational costs.[2]

In this paper, we propose an Analytic Hierarchy Process (AHP) for the multi-criteria evaluation of offshore wind site prioritization. In addition to the performance evaluation (expected energy yield), the proposed approach takes into consideration the technical impact of the candidate wind sites in term of security of supply as well as integrated energy efficiency (demand and supply conjunction, balancing needs).

The proposed approach is applied for a case study in the Baltic Sea, using a transmission simulation model for the 2020 year horizon. In Section 2, we introduce the proposed general framework starting from the preselection phase which is based on a predefined set of GIS layers to identify a limited set of candidate sites. Once the preselection phase is defined, we introduce the AHP evaluation criteria, the corresponding calculation methods, as well as a pairwise comparison methodology to define their contribution to the prioritization process. Section 3, describes in detail the implementation of the proposed site selection framework for the three Baltic States. Finally, in the Section 3.5, we present the results for each Baltic State based on the pairwise comparison to illustrate the impact of the criteria weighting in the prioritization process.

2. Site selection framework

The proposed site selection framework aims to investigate in systemic approach the interrelationship of criteria affecting an optimal selection of offshore wind sites taking into consideration relevant decision maker's priorities and preferences which are aggregated to reach a consensus prioritization. Fig. 1 illustrates a high-level flowchart of the proposed site selection framework consisting in three main steps: prerequisite data processing (depends on the local characteristics therefore addressed in detail in the Section 3), pre-selection phase, and finally the sites evaluation and ranking. The pre-selection process aims to constrain the potential candidates list taking into consideration effective boundaries confined by territorial, regulatory or technological limitations. The proposed selection criteria are identified into three objectives: (i) Reliability objective: impact on the electricity network security of supply in term of congestions and volatility, (ii) Cost objective: impact in term of investment cost and balancing reserves (TSO OPEX), (iii) Performance: expected energy yield and the correlation of wind profile patterns with coincident load demand. The interrelationship and relevance of each of the defined criteria are evaluated based on pairwise comparison to derive priority scale taking into consideration all the stakeholder's perspectives. It is important to underline that the proposed framework aims to investigate a prerequi-

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[2] Such costs could involve congestion management or balancing costs that are ultimately socialized in the final consumer tariffs, therefore affecting the customer surplus.

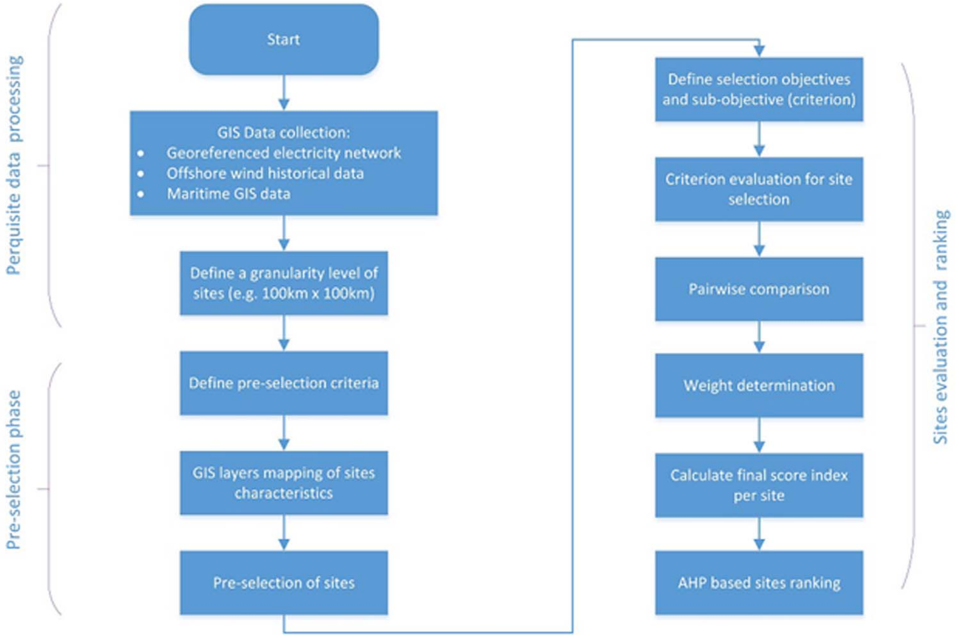

Fig. 1. Flowchart of the sites data processing and final ranking.

site ranking of potential wind sites against a defined list of criteria. In that perspective the final number of selected projects will depend on the investments funds availability and the local political targets in term of renewable energy resources penetration targets. Depending on local characteristics, the applied site selection framework might lead to poor performances specifically in term reliability and cost objectives. Such context provides specifically to electricity networks operators and relevant regulatory authorities investment signals for network reinforcement and adequacy mechanisms. Such insights are of important significance to policy and decision makers in term of targets feasibility and necessary reinforcements needs.

2.1. Prerequisite data processing

Wind site selection requires the consideration of a comprehensive set of aspects and objectives that would characterize the most attractive alternatives. Depending on the local characteristics in term of geological features, decision maker's priorities and regulatory frameworks; a set of prerequisite data shall be processed for a comprehensive evaluation of the candidate sites. Such data range from GIS layers used for planning pre-selection process to retain only valid and economically feasible sites to wind speed data and electricity network models to evaluate sites performances. GIS data are ideally processed taking into consideration a preferably small granularity level specifically for Wind speed vectors (historical data) that are converted and adjusted to the intended height of exploitation, as well base case model of the electricity networks both to be used to evaluate the yield of each potential site and its consequent impact on the electricity system. Beside the site specific characteristics, economic factors to evaluate the execution cost related to each of the candidate sites are also needed (e.g. implementation cost based on distance from the shore to opt for HVDC or AC variant and the resulting cost in term of connection…).

2.2. Candidate sites pre-selection

Once the prerequisite data processing is completed, the first stage for optimal wind site selection involves the delimitation of the relevant geographical locations. The restriction exercise can be the result of economic limitation, technological limitations, environmental limitations or regulatory aspects in general. Practically, this could be achieved by the definition of GIS layers which are mapped to form the intersection of the feasible sites. Table 1 illustrates common preselection layers covering offshore and onshore wind site applications. The layers used in the preselection exercise might further include technical feasibility constraints or economical limitation to bound the assessment of the site candidate using predefined thresholds. It is

Table 1
Examples of preselection GIS layers.

Name of the Layer	Nature	Limitation factor	Application
Water Depth restriction zones	Deep water limitation threshold for foundation structures	Technical	Offshore sites
Exclusive Economic Zones (EEZ)	Jurisdiction over the exploration and exploitation of marine resources	Regulatory	Offshore sites
Maximum radius from onshore assets	Distance between offshore farms and existing onshore assets mainly High Voltage substations	Economical	Offshore sites
Environmental restriction zones	Covering natural reserves and animal habitats conservation.	Regulatory	Offshore and Onshore sites
Heritage restriction zones (Sánchez-Lozano et al., 2016)	Covering archaeological, cultural and paleontological sites	Regulatory	Offshore and Onshore sites
Urban restriction zones	Visual intrusion, flicker and noise in the vicinity of habitations zones	Technical	Offshore and Onshore sites
Geological restriction zones (Van Haaren and Fthenakis, 2011)	Porous ground and high slopes resulting in foundations instabilities and landslide risks	Technical	Onshore sites

Heritage restriction zones (Sánchez-Lozano et al., 2016) Geological restriction zones (Van Haaren and Fthenakis, 2011).

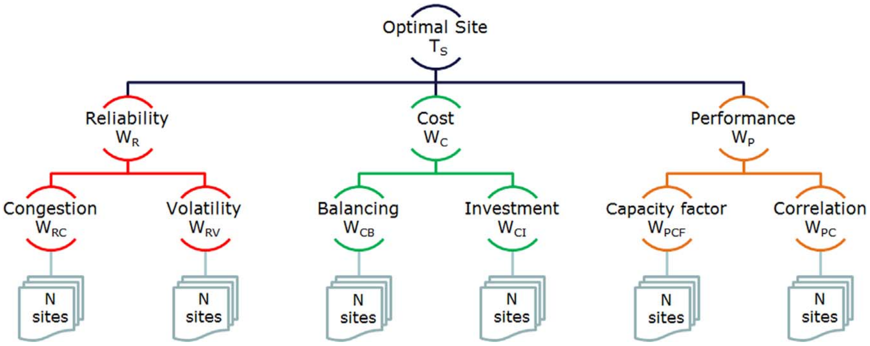

Fig. 2. Decision making based on Analytic Hierarchy Process.

important to underline that the threshold limits used to define the geographical filters in the pre-selection phase depend on the characteristics of the assessed region, the expected installed capacity and the state of the art of the technological evolution (cost of cables, converters, and technological innovation). The intersection of the all the layers will result in the final considered geographical regions; potential projects located within these areas will be prioritized as candidate alternatives using the AHP methodology.

2.3. Criterion definition for the Analytical Hierarchy Process

The AHP proposed by (Saaty, 1990) is a simple mathematically based multi-criteria decision-making tool to investigate complex, unstructured and multi-attribute problems. The AHP method is used to derive ratio scale priorities from approximate pairwise verbal comparisons relative to any attribute (quantitative or qualitative). The AHP method presents the advantage of systemic complex decision making problems by capturing both subjective and objective evaluation measures broken in a hierarchical fashion. The current decision problem, consisting of the choice and ranking of the best candidate sites for off-shore wind power parks, is structured hierarchically by defining coherent objectives and sub-objectives. Each identified sub-objective can be prioritized depending on the relative significance to the user.

Fig. 2 illustrates the proposed AHP, including the sets of identified objectives and sub-objectives aiming at assessing the suitability of each alternative. Each criterion reflects a key performance metric of each candidate project (benefits or risks), covering the financial impact as well as the direct impact on the security of supply (based on electricity network simulations). Weights allocated to each sub-objective reflect their importance in achieving the final goal - they are determined through pairwise assessments by interpreting their significance to the values pursued by each relevant stakeholder. The criterion identified in the performance objective reflects the producer surplus. On the other hand, the criterion identified in the reliability and the cost objectives reflects the consumer surplus via a proxy, reflecting the OPEX and CAPEX costs that are socialized on the electricity tariffs. The proposed AHP process allow more flexibility by including or excluding further criterion or objectives when deemed necessary to reflect specific characteristics of the assessed geographic region or particular regulatory framework, allowing a wind sites assessment under different sensitivities.

$$T_s = OP_s + OR_s + OC_s \tag{1}$$

$$T_s = W_{RC}C'g_s + W_{RV}V'_s + W_{CB}B'_s + W_{CI}I'_s + W_{PCF}Cf'_s + W_{PC}C'r_s \tag{2}$$

The defined objectives in Eq. (1) and their respective sub-objectives are summed up to calculate the overall score for each of the assessed potential site for offshore wind parks as per the Eq. (2), where all the criterions are weighted to reflect their significance in the decision-making process. For each assessed alternative, a final score (T_s) is calculated to establish the ranking of the sites and their suitability for implementation. In the following section, we introduce in detail the evaluation method for each of the defined criterion.

2.4. Criterion evaluation for site selection

2.4.1. Reliability objective

2.4.1.1. Congestion criterion. This criterion reflects the impact of each candidate project in respect of congestions in the electricity network following contingencies events. Standard power flow simulation tools can be used to develop a steady state transmission network model that will incorporate all the candidate sites, where the points of common coupling are defined in the closest onshore substation. To the resulting model, a contingency analysis is applied (loss of lines/cables, generators and transformers) to investigate the congestion effect of the non-dispatchable wind generation compared to the baseline scenario (without wind farms). Congestion can be critical during normal operation as it might result in tripping of lines that might lead to further domino effect degradation. Furthermore, congestion generates extra operational cost as re-dispatching costs or penalties related to generation curtailment. Eq. (3) represents the calculated congestion metric P_C^{Sys} for a single contingency event expressed in MW, consisting of the sum of all branches' overloads (e.g. transformers, lines, coupling) within the control area accommodating the candidate wind farm site. Once all the contingencies are executed (N is the total number of contingencies events), the total congestion level is calculated by summing all the overloads per each single contingency event as expressed in the Eq. (4). The final congestion criterion to be used as input for the AHP is the conjugate of the rescaled values calculated in the Eq. (5) within the range [0–1].

$$P_C^{Sys} = Tl_{j,k} \sum_{j=1,k=1}^{m,n} \Delta Ld_{j,k}\% \tag{3}$$

$$Cg_s = \sum_{i=1}^{N} P_C^{Sys} \tag{4}$$

$$C'g_s = 1 - \frac{Cg_s - Cg_{min}}{Cg_{max} - Cg_{min}} \tag{5}$$

2.4.1.2. Wind volatility criterion. Although balancing, in term of wind power fluctuation, can be interpreted as a purely economic constraint (as per the cost criterion defined in the Subsection 2.4.2) another dimension reflecting the impact on the security can be gauged alike. In fact, wind speed volatility could result in an increasing stress on primary reserves (frequency control), such short-term unbalances must be recovered rapidly (by adjusting the production in the interval of 0–30 s) to keep the frequency within the acceptable ranges.[3] Problems

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[3] For the European synchronous area primary reserves have been sized as 3GW which

would arise when a high share of off-shore wind farms are being installed in limited areas as the example of the European North Sea, while most of the primary reserves are located elsewhere throughout the synchronous area. This would further result either in an insufficiency of primary reserve means or overloading of cross-border lines carrying out reserves from other control areas.

To reflect the wind speed volatility in each of the assessed candidate sites, we measure the variance of the historical registered wind speed and adjust it to the expected capacity factor - Eq. (6) - to reflect the impact in terms of power fluctuation (i.e. a site with higher capacity factor will solicit more frequency reserves). Eq. (7), presents the variance criterion, which consists in the conjugate of the rescaled values calculated in the Eq. (6).

$$V_s = Cf_s \frac{\sum_{i=1}^{N}(u_i-\mu)^2}{N-1} \tag{6}$$

$$V'_s = 1 - \frac{V_s - V_{min}}{V_{max} - V_{min}} \tag{7}$$

Finally, the reliability objective R_s can be jointly formulated as following, where each criterion is adjusted to its respective weight that is reflecting its significance with respect to the other criterions.

$$R_s = W_{RC}C'g_s + W_{RV}V'_s \tag{8}$$

2.4.2. Cost objective

The cost sub-problem is mainly composed of two criterions that are reflecting mainly the CAPEX and the OPEX impacts, making up almost all of the investment and operational cost needed. The first criterion is the direct investment costs covering specific costs supported by the investor (in some cases jointly covered by the TSO), while the second criterion represents the balancing costs needed to maintain the demand and supply balance within the respective control area. The maintenance cost (OPEX) are not considered as it is difficult to assess the relative cost that depends on the location of the project and contractual matters. However, the flexibility of the site selection framework allows the inclusion of such cost if they are judged relevant to the decision-making process.

2.4.2.1. Investment criterion. The investment expenses are calculated based on benchmark data for electrical equipment (transformer, substation, shunts and reactive power control means), interconnection, commissioning and decommissioning costs. With the exception of the direct cost of the equipment (we consider these equal for all candidate sites – identical installations), the remaining CAPEX investments depend mainly on the geographical nature of the wind farm site. Such costs depend on the distance to the onshore substation (e.g. length of cable, reactive power and voltage control equipment) and the water depth in the candidate wind site area (i.e. mainly for the platform installation).

The GIS data used for the first preselection phase (Subsection 2.2) will be used in this stage to estimate the expected cost for each candidate wind site connection (cable length) as well as identifying the type of technology to be used for each project: AC or DC connections (distance from onshore substation), floating or anchored platforms (water depth). The estimated costs for all the projects are normalized, while the conjugate of the rescaled values is considered as the final output of the investment criterion as expressed in the Eq. (9).

$$I'_s = 1 - \frac{I_s - I_{min}}{I_{max} - I_{min}} \tag{9}$$

2.4.2.2. Balancing criterion. A sustained increase in wind generation installed capacity, could result in exacerbation of the volatility effect (typically when generation is confined within a limited geographical space), thus requiring further flexibility needs in term of generation balancing. This is reflected by higher constraints on automatic frequency restoration reserves to accommodate the variability and uncertainty present in the wind power generation resulting of generation forecasting inaccuracy. Units providing such ancillary services must be contracted in year-ahead procurement or in more short term intervals (monthly auction). While it is difficult to monetize such impact as it depends on the respective market design, the demand and supply condition. The impact, however, could be estimated by assessing the variability of the net load in each control area taking into consideration an assumed connected wind capacity and using historical wind speed measurement.

$$\Delta_{NL} = NL_{i+1} - NL_i = (L_{i+1} - Pw_{i+1}) - (L_i - Pw_i) \tag{10}$$

A commonly used method to estimate the increase in balancing needs is based on the difference of the net load variation as expressed in the Eq. (10) where further statistical metrics could be used to establish a confidence level (Holttinen et al., 2008). In the present approach, although the balancing needs presented in the Eqs. (10) and (11) are not directly quantified in financial terms, the expected balancing requirement for each site could be reflected based on the wind time series variability against the load demand profiles. The balancing cost expressed in the Eq. (12), consists in the increase of a multiple of the standard deviation[4] difference between the net load and the base load demand with a confidence margin of 99%.

$$\sigma_{NL} = \sqrt{\sigma_L^2 + \sigma_W^2} \tag{11}$$

$$B_s = 4(\sigma_{NL} - \sigma_L) \tag{12}$$

$$B'_s = 1 - \frac{B_s - B_{min}}{B_{max} - B_{min}} \tag{13}$$

The balancing criterion is normalized as described in Eq. (13), the total cost objective C_s can be formulated as per the Eq. (14), by summing the weighted balancing and investment criterion.

$$C_s = W_{CB}B'_s + W_{CI}I'_s \tag{14}$$

2.4.3. Performance objective

The performance sub-problem reflects the energy yield of each candidate wind site as well the effectiveness of generation profile throughout the year. The first criterion consists in the capacity factor corresponding to each candidate wind site; the second criterion reflects the correlation between the load and the wind power generation (within the served control area). In fact, the second criterion is more of interest to the TSO in term of generation adequacy rather than the wind power producer which is more sensitive to the first criterion.

2.4.3.1. Capacity factor criterion. The wind capacity factor of a candidate site is one of the most relevant criterions to be considered by the investor as it would have the biggest impact on the expected investment returns. The capacity factor corresponds to the ratio of the power generated by a wind farm - over a period of time - to its potential output at full capacity. Due to the non-linear characteristics of generated power under variable wind speeds, the mean power

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(*footnote continued*)
corresponds to the double loss of the largest two generation units. The reserves are actually distributed within the member states in a pro-rata factor of the previous year total generated power.

[4] A normal distribution is a measure reflecting how spread a population of numbers is, where 68% of the values are within one standard deviation of the mean (1σ), 95% is covering two standard deviations of the mean (2σ), and 99.99% would be covering four standard deviations of the mean (4σ).

obtained over time under a mean wind speed would be different from the real generated power. In order to cover extensively the expected wind, historic measurements are used to establish a probability density function allowing to have a robust evaluation of the expected power generation and capacity factor for each of the assessed sites (Fig. 3).

$$f(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} e^{-\left(\frac{u}{c}\right)^{k}} \tag{15}$$

A wind turbine generally operates within four operational modes limited by the points *A*, *B* and *C* illustrated in Fig. 4: (i) for wind speeds lower than point A (referred commonly as the cut-in wind speed) the torque exerted on the turbine blades is insufficient to generate an electrical power output, (ii) for wind speeds between *A* and *B*, the generated power increases with the wind speed -as expressed in the Eq. (16), (iii) for wind speeds between B and C (C being commonly referred as the cut-out wind speed) the power output reaches the limit that the electrical generator is capable of producing - which is equal to the rated capacity of the turbine, (iv) for wind speed higher than the point *C* the wind turbine will trigger internal protection mechanism to block the rotor, which would result in no power generation.

$$P(u)=\frac{1}{2}\rho A u^{3} C_{p} \tag{16}$$

Once the wind speed probability distribution for each site is defined, the characteristics in the Eq. (16) are used to derive the proportion of time (probability) under which a wind farm produces a certain level of power. The capacity factor for each site could be finally expressed as the integral of the probability of each wind speed multiplied by the equivalent generated power over all the range of wind speeds divided by its potential output under full rated capacity operation - Eq. (17). The input finally considered as a criterion in the AHP model is normalized as described in the Eq. (18).

$$Cf_{s} = \int_{u_{min}}^{u_{max}} \frac{P_{s}(u).\, f_{s}(u).\, du}{Pmax_{s}} \tag{17}$$

$$Cf'_{s} = \frac{Cf_{s} - Cf_{min}}{Cf_{max} - Cf_{min}} \tag{18}$$

2.4.3.2. Correlation criterion. The capacity factor reflects the capability of a potential wind site to provide a high and consistent level of power generation - thus reflecting the expected profit of the owner. On the other hand, little attention is paid to the correlation level between the availability of wind power generation and the load demand which is not reflected by the capacity factor index. In fact, depending on the geographical location and meteorological characteristics, each site is characterized by diurnal, monthly or inter-annual variability (Sinden, 2007). In this subsection, we introduce a criterion to assess the suitability of each wind profile patterns with respect to the coincident load demand. The goal is to identify a positive relationship for sites that present tendencies of higher productivity during peak load demands (daily or seasonal peaks - i.e. winter or evening peak) with respects to the sink points served by the wind farm. Mathematically the correlation criterion is expressed by the normalized correlation between the wind and the load profiles adjusted to the capacity factor as expressed in the Eqs. (19) and (20).

$$Cr_{s} = Cf_{s}\frac{\sum_{i=1}^{N}(u_{i} - \overline{u})(L_{i} - \overline{L})}{(N-1)\sigma_{W}\sigma_{L}} \tag{19}$$

$$Cr'_{s} = \frac{Cr_{s} - Cr_{min}}{Cr_{max} - Cr_{min}} \tag{20}$$

A site featuring a positive correlation between wind speed and demand profiles presents an added value on the capacity credit and the generation adequacy within the respective control area, while a negative correlated profile would be eventually ensuing adverse impact on the network adequacy (typically high wind power generation during low demand). Finally, the performance criterion is expressed in the Eq. (21) as the sum of the weighted capacity factor and weighted correlation criterion.

$$P_{s} = W_{PCF}Cf'_{s} + W_{PC}C'r_{s} \tag{21}$$

2.5. Pairwise comparison and weight determination

To determine the contribution of the defined criterion and their dominance with respect to the other ones, each criterion is compared in term of significance not only from a single stakeholder perspective but with respect to the overall impact of the project on the grid users. In a multi-criteria decision making, criterions discrepancies (with respect to their mutual dominance) are commonly faced, resulting in some scenarios that are exhibiting rank reversal when adding or deleting certain options.

Pairwise comparison is used to determine the relative importance of each sub-objective, where the involved stakeholders or experts define a one-to-one mapping between all the identified sub-objectives by a discrete set of numbers reflecting their importance.

The proposed AHP pairwise comparison process can involve multiple stakeholders that can be generally grouped into four groups. The first group would reflect the regulatory authorities aiming to leverage an efficient integration of renewable energies and compliance to the existing regulatory aspects. The second group reflects investors consisting of financial organizations or producers lobbying associations mostly interested in securing revenues through higher production yields and minimum investments cost (maximizing the net present value of projects). The third group represent electricity networks operators that might include Distribution System Operators (depending on the voltage connection level), TSOs or Independent System Operators, aiming to reflect the operational impact of the candidate sites either technical or financial terms. Finally, the last group would represent the local authorities, civil society and environment preservation organizations. Such group input could be either considered in the pairwise comparison which might result naturally in conflicting preference and therefore in a lower consensus level. A second alternative would be to take their preference in the preselection stage (as defined in the Table 1), this option while resulting in purely exclusive constraints (e.g. minimum distance from onshore lines) have the advantage to mitigate social acceptance risks and subsequent permitting issues.

The relative simplicity of the pairwise comparison process allows the elicitation of reference for objectives and criterion by stakeholders groups which could be achieved via public consultation tools. The final

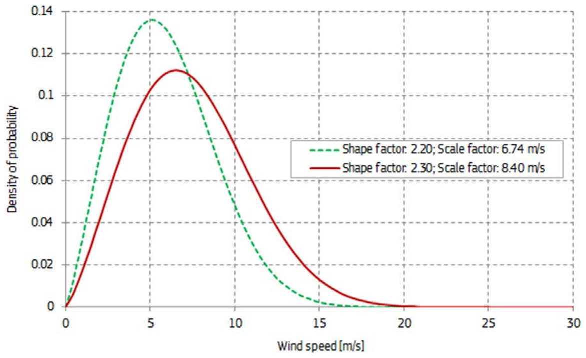

Fig. 3. Weibull distribution functions for two wind measurement sites Weibull probability density function is commonly used to define wind speed continuous probability distribution function (Lun and Lam, 2000; Sinden, 2007; Weisser, 2003). A Weibull function is defined mainly by its shape parameter k and scale parameter c, as illustrated in Fig. 3 for two distinct sites. These two parameters determine the wind speed probability distribution from a measured dataset allowing a better understanding of the optimum wind conversion system selection as well as the speed range over which the wind turbine is likely to operate as given in the Eq. (15):.

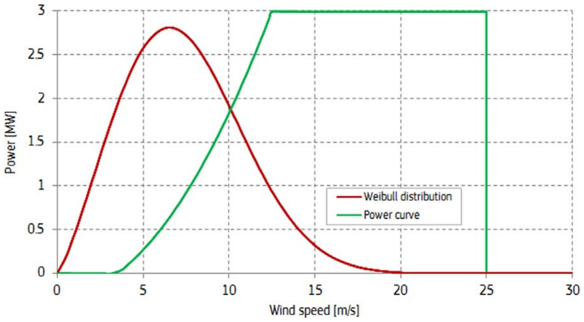

Fig. 4. Weibull distribution function and wind turbine power output function.

weight determination and the overall consensus level will therefore depend on the involved stakeholders in the consultation and the pairwise comparison process.

The values of the pairwise comparisons in the AHP are determined according to the scale introduced by (Saaty, 2000) composed of a set of discrete values for the pairwise comparisons defined in Table 2. For example, when comparing criterion A with respect to a B criterion: if A is judged strongly more important than B - 5 is assigned, inversely if B is judged strongly more important than A - 1/5 would be assigned. The comparison is summarized in a NxN matrix where N is the number of the identified criterions, each cell would represent the importance $a_{i,j}$ of the criterion in row i with the corresponding one in the column j resulting in a square matrix (with the value 1 in the diagonal elements).

For a decision-making process involving several parties with different appreciation level or merit order of criterions, all their inputs should be collected independently. Each participant in the decision-making process should submit their pairwise comparisons that are finally consolidated in a single comparison matrix by weighted geometric mean of all the decision matrices elements - provided a certain level of consensus is reached (Goepel, 2013). After the consolidated comparison matrix is formed, the Eigenvalue method is used to calculate a priority vector that represents the relative ranking of importance for the identified criterions. A Saaty's criteria (Saaty, 2000) defined the Consistency Ratio (CR) that should be calculated to validate or reject the caparison matrix, where values higher than 10% are considered unacceptable.

3. Application of the selection framework in the Baltic States

The proposed site selection framework has been applied for off-shore wind sites selection in the Baltic States (eastern coast of the Baltic Sea). Relevant pre-selection criteria has been proposed and applied for the sites pre-selection to set up feasibility boundaries and limit the candidate sites number. The detailed perquisite data processing for criteria evaluation is introduced in the current section:. the electricity network model will be used for the security of supply related criterion i.e. congestion impact, while the wind data record data are used to assess the balancing, capacity factor and correlation criterion.

3.1. Prerequisite data processing

3.1.1. Electricity network model in the Baltic States

The electricity networks of the Baltic States are tightly interconnected and integrated into the BRELL ring (Belarus, Russia, Estonia, Latvia, Lithuania) and are currently synchronously operated within the UPS/IPS zone. The integration of the Baltic States into the EU energy market has been identified as a strategic priority for all three countries. Such integration presents several opportunities in term of social welfare and security of supply. In this perspective, several challenges are expected on the long and the short term, mainly related to the EU central energetic goals - namely: security of supply, competitiveness and sustainability. Specifically, the renewable energy directive (Official Journal of the European Union, 2009) and the emission limitation directives (2001, 2010) will accelerate the path for faster deployment of renewable energy sources to reach the binding target of 20% of final energy consumption from renewable energy. The Baltic Sea presents a very high potential in term of off-shore wind power generation with a 2000 TWh potential not yet being fully used (Paist). To fulfil their National action plans, the three Baltic States are expected to reach an off-shore installed capacity of more than 430 MW by 2020 (Baltic Sea Region Energy Co-operation, 2011).

In the current study, each assessed candidate wind farm has an installed capacity of 100 MW. While a different capacity would not affect the scoring in term of reliability or performance, it is expected that higher share will necessarily require reinforcement or augmentation in term of balancing cost. Reinforcement costs can be covered in different ways depending on the regulation and market design - such costs would be covered by the producer (deep connection charges) or alternatively the producer will be only responsible for covering his own connection costs (shallow or super-shallow connection charges). Likewise congestion impact or balancing cost (ramping up/down) could be supported by the producer through curtailment or by the transmission network and ultimately socialized in the final consumer tariffs. It is worth mentioning that in either case the proposed approach is able to reflect such sensitivities while evaluating candidate projects, by adapting the contribution of the investment costs against the congestion criterion and the balancing costs at the stage of the pairwise comparison.

The developed transmission electricity network model (Fig. 5), includes Estonia, Latvia and Lithuania which are connected to the neighbouring countries modelled with simplified equivalent models (Russia, Belarus) as well as the HVDC links between Estonia and Finland, Lithuania and Sweden. Table 3 summarizes the current main figures of the electricity network model characterized mainly by an overall installed generation capacity of 9.75 GW and at total peak demand of 4.72 GW (ENTSO-E, 2014b).

The current transmission network has been upgraded to the expected 2020 time horizon considering the adequacy forecasting of each individual country in term of load and generation forecasting (ENTSO-E, 2014b). The model includes the expansions, reinforcements, commissioned and decommissioned power plants - as confirmed in the ENTSO-E TYND and the local TSOs investment plans (ENTSO-E, 2014a; c).

The security analysis (contingency analysis) introduced in the Section 2.4.1.1 - to determine the impact of installed wind generation on the congestion levels - is conducted using the coincident winter load peak demand snapshot, based on the provisions of the 2020 adequacy winter peak demand for each Baltic State (ENTSO-E, 2014b). The load granularity for each substation is scaled (top-down approach) starting from the global peak that is homogenously distributed using a historical snapshot of the BRELL network (under similar power factor condition).

Table 2
Scale of relative importance (Saaty, 2000).

Importance	Definition	Interpretation
1	Equal importance	Two sub-objectives contribute equally to the objective
3	Weak importance of one over other	Experience and judgment slightly favour one over another
5	Essential or strong importance	Experience and judgment strongly favour one over another
7	Demonstrated importance	A sub-objective is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one Sub-objective over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	A compromise is needed

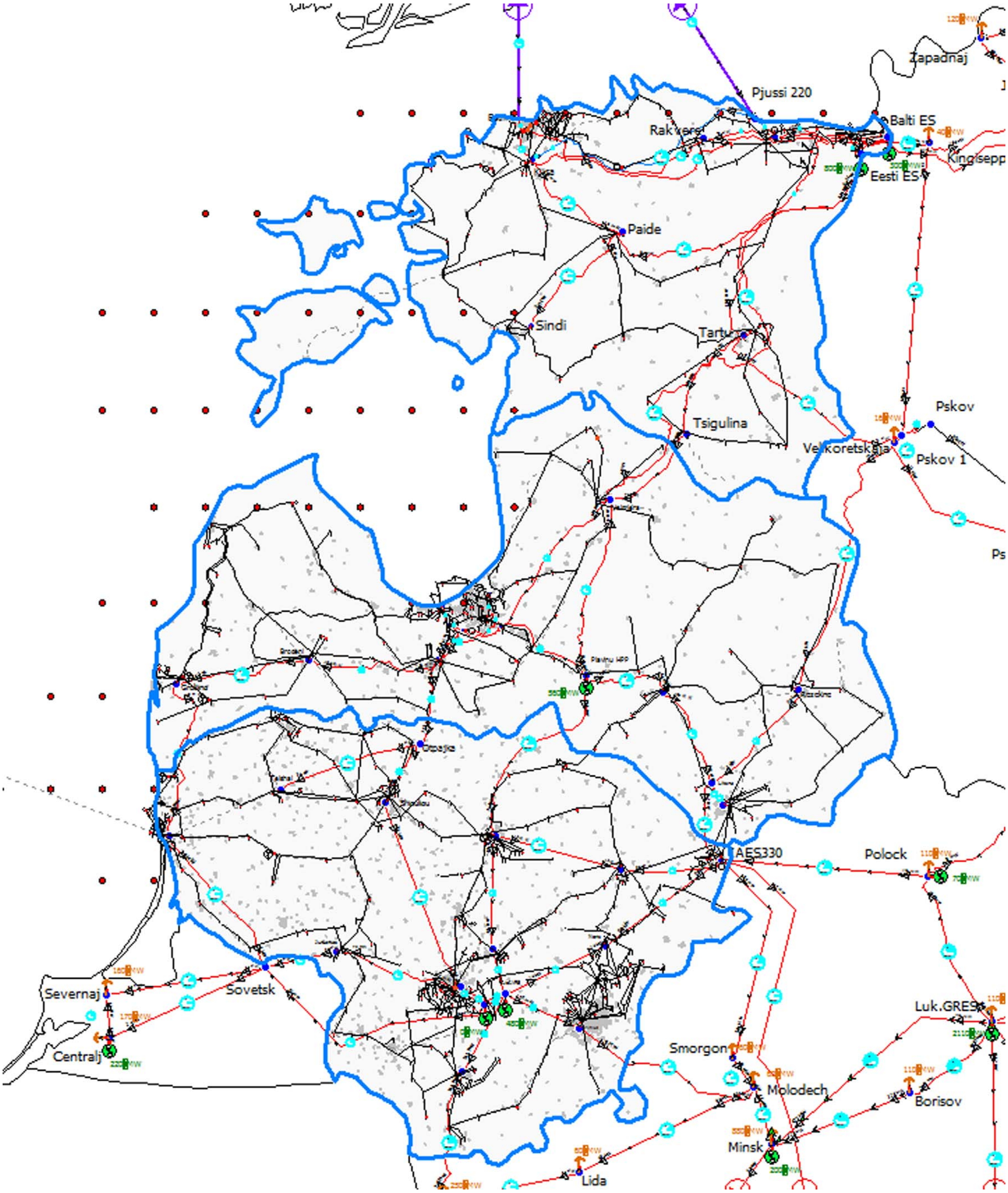

Fig. 5. BRELL ring power simulation model.

Table 3
Main figures of transmission network model in the Baltic States.

Country		Estonia	Latvia	Lithuania	All
Generation capacity [GW]		2.60	3.05	3.80	9.45
Peak load [GW]		1.51	1.36	1.85	4.72
Substations (110/330 kV)		136	234	146	1307
Lines [km]	110 kV	3423	4010	4966	12399
	220 kV	158	–	–	158
	330 kV	1535	1535	1672	4457

3.1.2. Wind data records in the Baltic States

To determine the wind parameters a series of steps had to be taken. The raw data was extracted from The European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim dataset. ECMWF is an independent intergovernmental organisation supported by 34 states. ERA-Interim is a global atmospheric reanalysis from 1979, continuously updated in real time (The European Centre for Medium-Range Weather Forecasts). The spatial resolution of the global atmospheric and surface parameters set is approximately 80 km on 60 vertical levels from the surface up to 0.1 hPa. The dataset includes 6-hourly atmospheric fields on model levels, pressure levels, potential temperature and potential vorticity.

The raw wind data originates as u and v vectors (10 m). The meteorological convention for winds is that the zonal velocity component is positive for a west to east flow (eastward wind) and the meridional velocity component is positive for a south to north flow (northward wind). Using the two components, both the speed and direction of the wind can be calculated. We determine the magnitude of the wind vector by using the Pythagorean Theorem.

The wind speeds at the height of a turbine (ca. 100 m) must be estimated from near surface wind observations (10 m). To achieve this we use the wind profile power law (Irwin, 1967) - a relationship between the wind magnitude at one height, and that at another.

The wind speed u_i at height z is estimated using the known wind speed u_r measured at a reference height z_r while the exponent α is an empirically derived coefficient that varies dependent upon the stability of the atmosphere. For offshore wind farms, α is approximately 0.11 (Hsu et al., 1994). The value of α is assumed to be constant in wind resource assessments because the differences between the two levels are not usually so great as to introduce major errors into the approximations. When a constant exponent is used, it does not account for the roughness of the surface or other obstacles. However, for offshore wind turbines, there are no trees or structures impeding the wind.

The raw wind data[5] used for this study extended over 5 years of measurements (2009–2013) and covered the exclusive economic zones of the Baltic states with a resolution of 0.5 degrees. Since the wind speed records had a 6-h resolution a linear interpolation was performed to generate hourly records.

An annual wind profile was calculated for each zones by averaging the wind speed values (Fig. 6) by location and time of year (i.e. 1st Jan. 2009 12AM with 1st Jan. 2010 12AM). Before the average was calculated the values with standard deviations (per location and time of year) were removed from the batch. These few values showed unrealistic wind speeds because of meteorological instrumentation recording or processing errors (e.g 120 m/s wind speed).

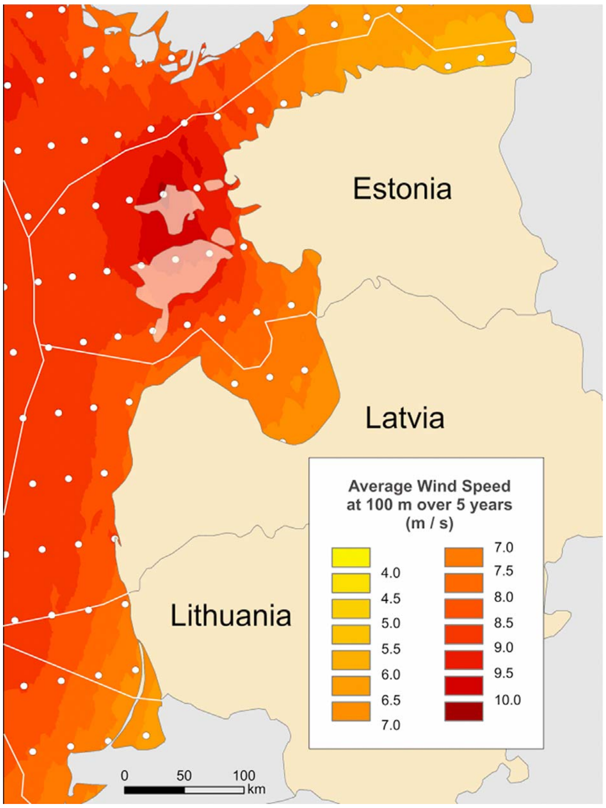

Fig. 6. Offshore average wind speed at 100 m above sea level.

3.2. Pre-selection of wind potential sites in the Baltic States

3.2.1. Geographical preselection criteria

3.2.1.1. Water depth restriction zones. The Baltic Sea is rather a shallow sea with smooth slope seabed, low coastline and without major bathymetric irregularities. It imposes no major difficulties in technical implementation of wind exploitation projects which provides it with a vast economic potential.

However, the techno-economic constraints determine to limit the search for most suitable areas to depths less than 60 m. Considering the current technical conditions, beyond this depth the building and maintaining costs of the wind farms would be too large which leads to diminishing or even cancelling the economic profitability. In future with the advent of new techniques or with a decrease in implementation costs this depth could be reconsidered. Environmentally this condition is one of the most important that strongly limits the areas' suitability to economic usage.

For the bathymetric analysis, we used the ETOPO1 digital model produced by National Oceanic and Atmospheric Administration (NOAA) in 2008 (Amante and Eakins). Its horizontal resolution of one arc-minute and vertical of 1 m has the appropriate degree of detail to yield an accurate result. The surface resulted after the filtering covers a wide area which extends up to 50–60 km from the shore.

3.2.1.2. Exclusive economic zones. Most of the off-shore related economic activities including wind energy production are only possible within the limits of the EEZ where the states have sovereign rights for exploiting natural resources (United Nation, 2013). The site selection criteria in our analysis limit the potential suitable areas for wind production to the stretches inside EEZ adjacent to the countries for which the analysis is carried (Flanders Marine Institute, 2014).

3.2.1.3. Maximum radius from onshore assets. The electrical power produced by the wind must be transported to the shore using electrical cables laid on the seabed. It implies special building techniques and costs that account to the distance from shore. On shore, the connection must be made with an existing substation in order to deliver power to the national grid. Substations with 110 kV and above voltage levels were considered and a limit of 60 km around them was set in order to search for favourable off-shore areas. The high capacity to integrate and handle new substantial power injection into the grid was the main reason to consider the chosen voltage level threshold.

The list of substations comes from the JRC Institute for Energy and Transport (JRC-IET) internal database which is a compilation of PLATTS and Baltic countries TSOs databases.

3.2.2. Resulting sites pre-selection

The layers corresponding to the three identified conditions were intersected yielding the common area comprising the candidate sites. Based on available spatial resolution of the wind dataset (80 km×80 km), within the exclusive economic zone of the Baltic countries, 56 wind data zones are present. Considering the bathymetry and the distance from shore (but still inside the EEZ) 23 zones are within the area with a water depth less than 60 m and a distance from shore less than 60 km. All 56 wind data zones are analysed in order to have a wider view of the wind power potential for zones whose building and implementation costs might be higher but which in turn could prove to be more profitable in the long term due to higher sustained wind speeds (Fig. 7).

3.3. Criterion evaluation and Base case sites ranking

Site ranking results are presented for two scenarios, the first one reflect a neutral judgment on the relevance of each criterion (i.e.

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[5] The raw wind (CSV) data can be downloaded from the following address: http://europa.eu/!dY33Xj.

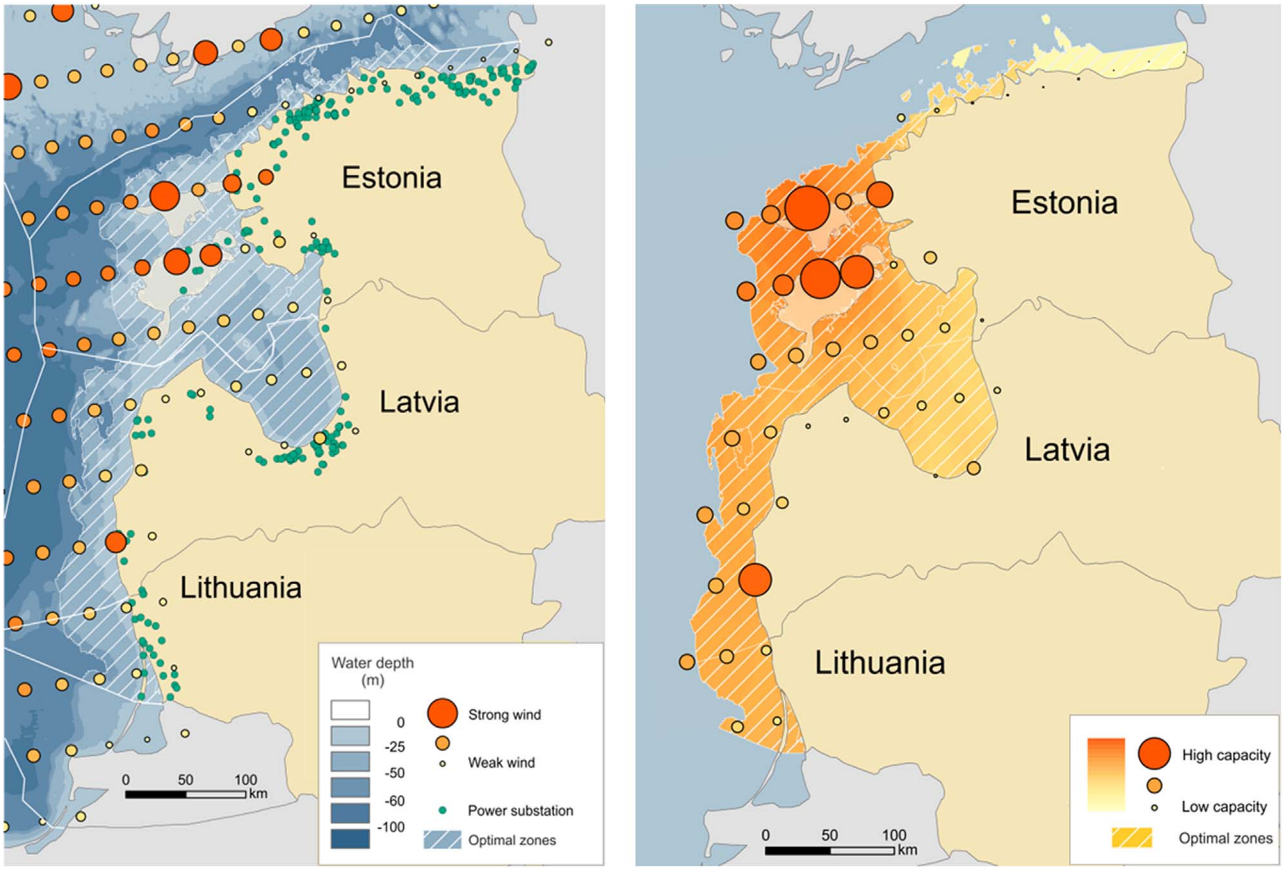
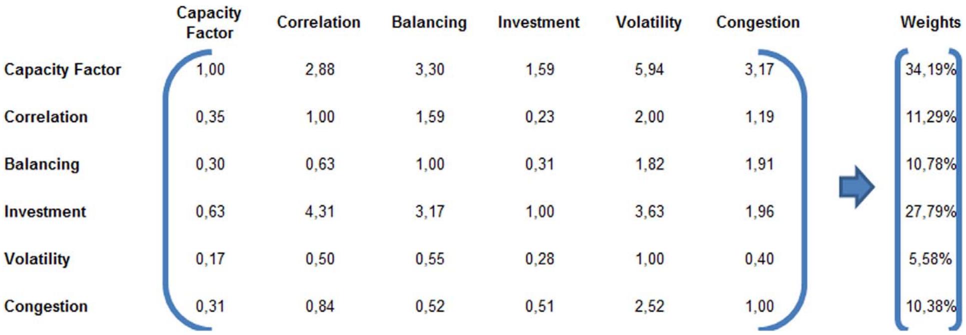


Fig. 7. Wind sites selection using GIS data.

homogeneous weights) - in such case all the criterions are reflecting an equal contribution for the selection of the best candidate site. The second scenario presented in the Section 3.4 is based on the pairwise comparison, where the scoring of the defined objectives (and their respective criterions) are adjusted with different weights reflecting a consolidated appreciation of all the identified stakeholders. It is worth mentioning, that the site ranking outcomes will depend on the defined criterion and the preferences of the stakeholders driven by their respective interests.

In the present scenario, the final score T_s calculated in the Eq. (2) constitutes the average of all the criterions scoring. Fig. 8 represents a spider-web chart summarizing the scoring of top performing candidate sites. The highest scoring has been achieved in Estonia comparing to sites in Lithuania and to less extend to the ones in Latvia (ranking and scores are summarized in Annex A1). This could be mainly explained by the high wind speed availability and the easiness to connect to the existing onshore substations. Such approach however, does not reflect the relevance of the perused objectives, resulting in the selection of candidate projects that are not necessarily representing the best alternative if considering the global impact (e.g. site Estonia 31 and Latvia 09 selected due to attractive cost and reliability objectives while having a low scoring with respect to the performance objective). The Estonian sites presented homogeneous scoring due to their higher wind profiles availability and the ability of the network to accommodate power injection in those specific area characterized by high wind yield in the horizon of the study. It is worth mentioning that the actual congestion criterion is reflecting the foreseen situation of the network without considering a dedicated investment for further reinforcement aiming to limit the congestion effect. As an example, the site 4 in Lithuania, presents very high impact on the network congestion (low congestion scoring), the current site selection framework could provide a sensitivity analysis by including extra reinforcement projects to



	Capacity Factor	Correlation	Balancing	Investment	Volatility	Congestion	Weights
Capacity Factor	1,00	2,88	3,30	1,59	5,94	3,17	34,19%
Correlation	0,35	1,00	1,59	0,23	2,00	1,19	11,29%
Balancing	0,30	0,63	1,00	0,31	1,82	1,91	10,78%
Investment	0,63	4,31	3,17	1,00	3,63	1,96	27,79%
Volatility	0,17	0,50	0,55	0,28	1,00	0,40	5,58%
Congestion	0,31	0,84	0,52	0,51	2,52	1,00	10,38%

Fig. 8. Highest ranking sites for all the three Baltic States – Base case.

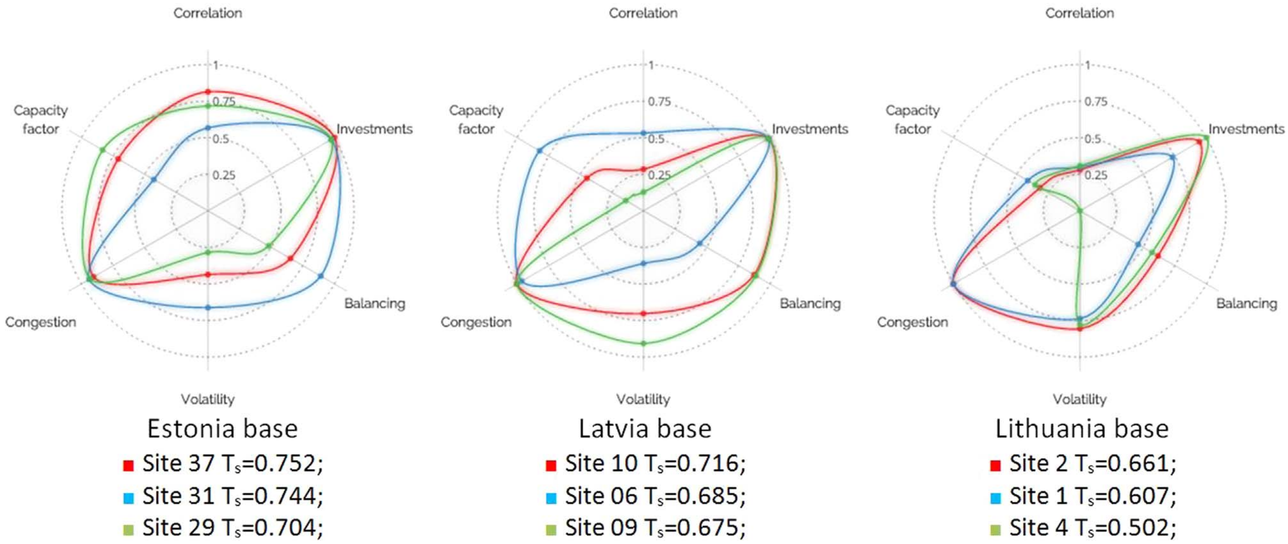


Fig. 9. Comparison matrix and resulting normalized eigenvector.

mitigate the congestion effects as part of the investment criterion scoring while taking in consideration the cost allocation practice in the respective control area (as described in the Section 3.1.1).

3.4. Stakeholders pairwise comparison and weight determination

Three possible preferences were selected for the pairwise comparison where each one reflects the interest of three identified stakeholders groups as per the detailed description in the Section 2.5. The pairwise comparison contributors are the producer/investor, the regulator and the electricity network system operator; naturally each actor would prioritize the identified criterion in the order of his own significance. It is important that all possible participants have a common understanding of each criterion and its direct impact on the other stakeholders where good consensus could be reached through joint workshops and eventually several iterations of the overall process. The pair-wise approach does not result in full consensus but synthesizes a representative outcome from the diverse judgments. An Eigenvalue method (Saaty, 2000) is used to calculate a priority vector that represents the relative ranking of importance for the identified criterions. The Fig. 9 illustrates the resulting comparison matrix and the final weight assigned to each criterion that is obtained by weighted geometric mean of all individual preferences. The matrix is characterized by 6% consistency ratio –a consistency ratio lower than 10% is considered acceptable - and 81% consensus among the three preferences. The resulting eigenvector (weights) reflects the highest importance of the capacity factor criterion, followed by the investment one. On the other hand, the congestion and volatility criterion were identified as the least imperative criterion in reaching the overall goal of the finest site selection.

3.5. AHP based sites ranking

Fig. 10 illustrates a spiderweb chart summarizing criterions scoring of the top candidate projects in the three Baltic States as er the second scenario taking into consideration the pairwise comparison. The criterions weights, resulted in higher significance mainly for capacity factor and investment comparing to the volatility one, this had an impact on the final prioritization of the candidate sites comparing to the base case scenario (Fig. 8). Considering the case of Estonia, based on the pairwise comparison new sites have been included in the top 3 ranking (i.e. site 35 and site 38), this is explained by their better scoring mainly with respect to capacity factor while having lower scoring in term of balancing and volatility (comparing to the site 31 and the site 28). As for the Latvian candidate site selection, the site 12 is included in the top 3 ranking comparing to the base case scenario due to its better scoring in term of capacity while presenting lower balancing and volatility criterions (comparing to the site 9). Finally for Lithuania no change in the ranking of the sites comparing to the base case scenario due to the similitude of the performances in the entire assessed sites mainly due to the very limited geographic spread.

Fig. 11 illustrates the wind speed histogram for the highest scoring candidates in the three Baltic States, where the Estonian sites have the highest wind speed standard deviation of 5.9 m/s with a mean value of 12.77 m/s. On the other hand, the assessed sites in Lithuania present lower wind speeds under quite similarly profiles (due to the limited geographic spread), where the lowest performing site has been characterized by a wind speed standard deviation of 3.55 m/s with a mean wind speed value of 7.5 m/s.

Fig. 12 illustrates the duration curve of the power generated (per unit) for the top three sites in the Baltic States. The power generation has been calculated considering standard characteristic of 2 MW rated capacity wind turbine - 4 m/s cut-in wind speed, 26 m/s cut-off wind speed and 14 m/s rated capacity wind speed. The obtained power generation profiles do not take into consideration unavailability for maintenance or forced outages. The wind sites in Estonia achieved the highest production yield averaging 70% probability of production levels higher than 40% of the installed capacity and 40% of probability of production at full rated capacity. Latvian selected wind sites achieved relatively lower production yield averaging 52% probability of production levels higher than 40% of the installed capacity and 28% probability of production at full rated capacity. It is clear that for the Estonian and the Latvian sites, the respective production yield has played an important contribution to the selection of the best candidate sites due to the variance of wind profiles in the available candidate sites. On the other hand as the Fig. 12 shows the Lithuanian candidate sites have quite low and very similar production profile with 35% probability of production lower than 20% of the total installed capacity, this resulted in a ranking mainly based on the merit contribution of the cost and reliability objectives.

An interactive map presenting the base results can be accessed at www.europa.eu/!mY43Yg. On the same page the weighting factors can be changed, therefore allowing the assessment under multiple weight contribution scenarios. The interactive map shows the result of the case study and is valid only for the decision space of the defined criterions.

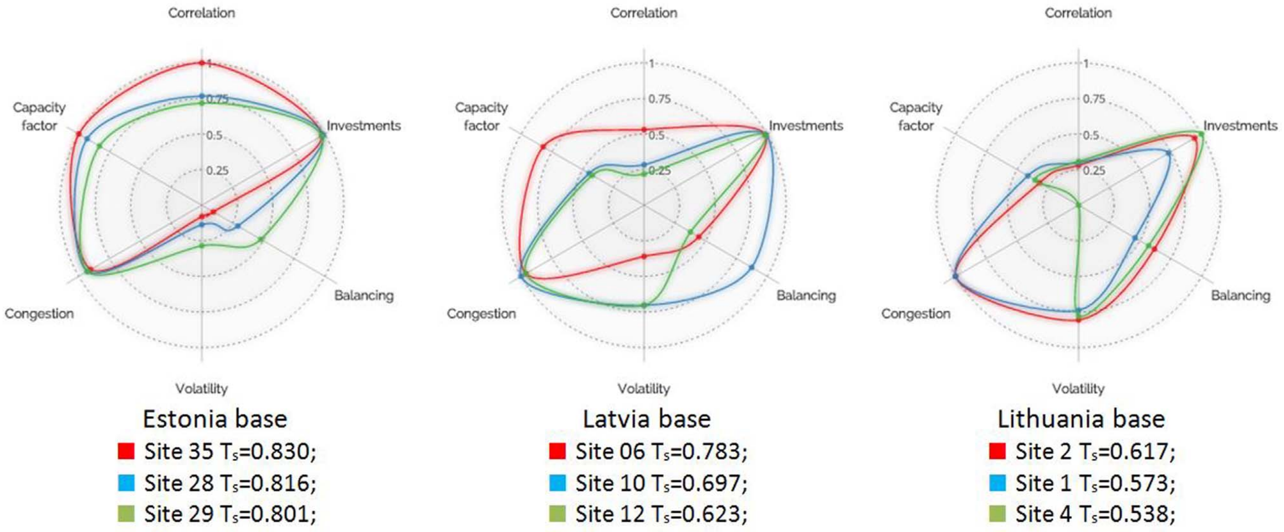


Fig. 10. Highest ranking sites for all the three Baltic States - pairwise based.

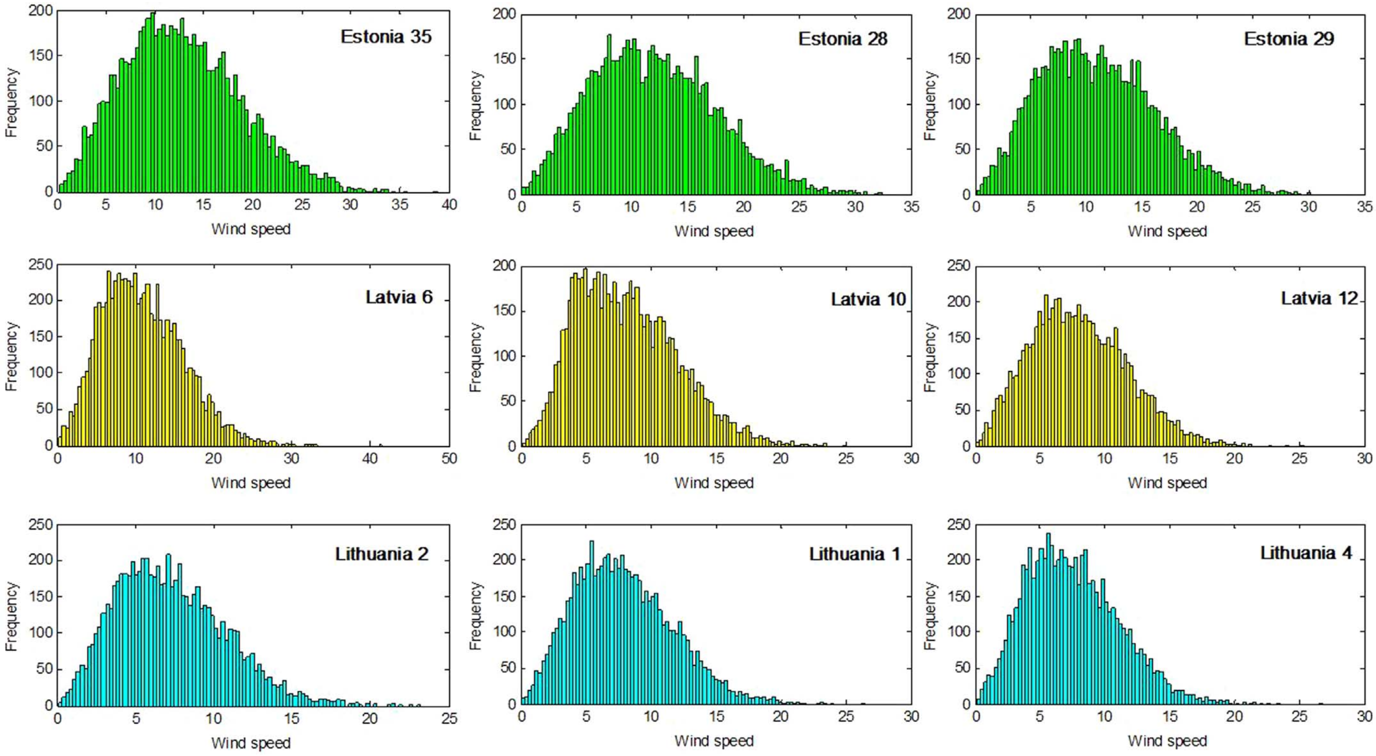


Fig. 11. Histogram of wind distribution in the top three locations per each Baltic State.

4. Conclusion and policy implications

In this paper, we propose a new framework for offshore wind sites assessment based on multi-criteria selection. The selection decision is made through AHP, aiming to allow decision makers (investors, regulatory authorities and electricity network operators) to adjust the selectivity weighting to reflect their respective and global priorities. The approach used for arbitration among the potential projects takes into consideration operational challenges of wind power integration by reflecting the physical impact of power infeeds on the electricity networks. The physical impact on the electricity network includes operating security aspects, economic investment, operation costs and adequacy contribution relative to each potential site.

The proposed assessment framework has been applied to a case study in three Baltic States with 2020 as time horizon, based on real geographical data and exhaustive power network models taking into consideration the foreseen upgrades and reinforcement scenarios. An interactive tool illustrating the case study outcomes with access to AHP weight factors is provided to allow users to apply different sensitivities and assess their implications in term of prioritization.

The site selection framework is quite flexible for adaptation to the local characteristics of the assessed projects, in order to reflect the characteristics of market design, regulatory aspects or renewable integration targets by adjusting each contribution factor through a transparent mechanism of prioritization aiming to jointly maximize the social welfare surplus of producers and consumers. The proposed approach, while being fully customizable (ponderation wise), it is mainly intended for classification of potential wind sites and allows

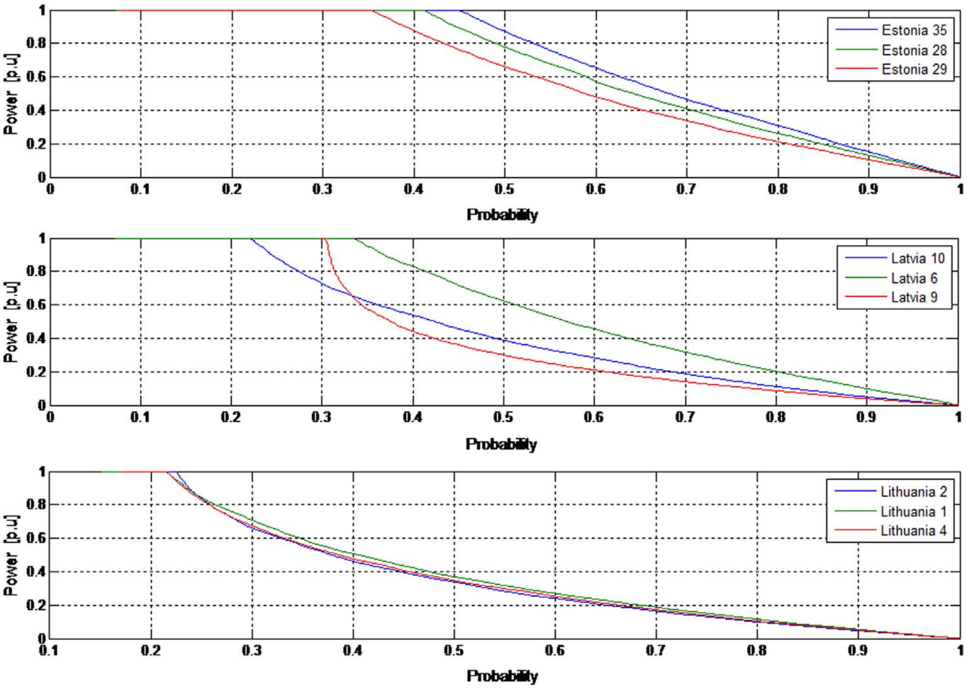


Fig. 12. Power generation duration curve for the top ranked sites.

the decision maker to take into consideration the security of supply and operational cost impact in the selection aspects. The proposed reliability criterion can be further exploited as investment signal for network reinforcement and balancing mechanisms to allow a higher penetration of off-shore wind capacity installation. Such insights are of important significance to policy and decision makers in term of targets feasibility and necessary reinforcements needs. Typically in a real life setting, a sensitivity analysis can be performed on the current approach, to gauge the performance of all the projects with and without further network reinforcement investment (new cables/lines, phase shifter transformers, dynamic line rating, storage, etc).

Acknowledgment

We would like to sincerely thank Dr. Marcelo Masera for his valuable comments and significant contribution to the improvement of the paper's quality.

Annex A

See Table A1.

Table A1
Base and scenario rankings.

Site number	Rank Base	Rank Scenario	Performance weights		Cost weights		Reliability weights		Base optimal site Ts	Scenario optimal site Ts
			Capacity factor	Correlation	Balancing	Investment	Volatility	Congestion		
Estonia 37	*1*	4	0.709	0.814	0.652	1.000	0.436	0.904	0.752	0.800
Estonia 31	*2*	5	0.428	0.567	0.892	0.975	0.662	0.938	0.744	0.712
Estonia 29	3	*3*	0.832	0.717	0.480	0.975	0.285	0.931	0.703	0.801
Estonia 25	4	14	0.147	0.321	0.889	0.944	0.895	0.925	0.687	0.590
Estonia 32	5	15	0.076	0.165	0.956	1.000	0.937	0.938	0.678	0.575
Estonia 28	6	*2*	0.933	0.767	0.293	0.988	0.137	0.931	0.675	0.816
Estonia 45	7	19	0.003	0.008	0.998	0.988	1.000	1.000	0.666	0.543
Estonia 35	8	*1*	1.000	1.000	0.094	0.975	0.000	0.904	0.662	0.830
Latvia 10	*1*	*2*	0.447	0.284	0.875	0.988	0.703	1.000	0.716	0.697
Latvia 6	*2*	*1*	0.821	0.531	0.445	0.988	0.360	0.962	0.685	0.783
Latvia 9	*3*	4	0.140	0.128	0.889	0.988	0.907	1.000	0.675	0.587
Latvia 12	4	*3*	0.421	0.219	0.377	0.988	0.703	0.962	0.582	0.623
Lithuania 2	*1*	*1*	0.316	0.280	0.617	0.944	0.806	1.000	0.661	0.617
Lithuania 1	*2*	*2*	0.413	0.299	0.460	0.732	0.738	1.000	0.607	0.573
Lithuania 4	*3*	*3*	0.354	0.307	0.570	1.000	0.779	0.001	0.502	0.538
Weights										
Base			1/6	1/6	1/6	1/6	1/6	1/6	Base	
Scenario			0.3419	0.1129	0.1078	0.2779	0.0558	0.1037	Scenario	

Appendix B. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2017.01.018.

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